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Technical Report 591

RETENTION OF ARMOR PROCEDURES: A STRUCTURAL ANALYSIS

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To determine the structure of memory for armor procedural tasks, proximity analyses (Friendly, 1979) were performed on verbal recall and hands-on performance of selected procedures. Structural analyses confirmed that armor crewmen organize their memory for procedures according to the hierarchical goal structures of the tasks. Comparisons of entry-level and field unit armor personnel showed significant decrements in skill performance over time; however, there were no systematic differences in memory structure between the two groups. Structures derived from verbal recall were highly indicative of hands-on

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structures for crewman still in training, but the relationship between verbal and hands-on structure was not as strong for armor crewmen in field units. Problems and implications of the structural analyses were discussed.

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RETENTION OF ARMOR PROCEDURES: A STRUCTURAL ANALYSIS

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FOREWORD

The Fort Knox Field Unit has a long history of applying behavioral research methods to problems in armor skill performance. As part of this effort, the Weapon System Training Team is specifically charged with research and development of methods for training armor skills.

Sophisticated armor systems require many complex procedures for operation and maintenance. There is a need to examine new training methods for these often difficult tasks. As a basis for training development, the present author described a cognitive model of procedural learning and memory. A structural analysis of armor crewman performance confirmed his basic theoretical notions. Implications of the structural analyses were also discussed.

This research should be of interest to training researchers and developers who are exploring new training methods. Although the example tasks are armor procedures, the model should apply to other types of procedures as well.

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RETENTION OF ARMOR PROCEDURES: A STRUCTURAL ANALYSIS

BRIEF

Requirement:

Armor tasks are changing in nature from skilled acts to tasks which are more procedural in nature. Research should be addressed to finding new methods for training and sustaining procedures. As a first step in the training development process, this report presents an analysis of memory structures which underlie retention of procedures.

Procedure:

Soldiers in entry-level armor training and armor crewmen in operational units were compared on their verbal recall performance and hands-on performance of procedures involving the M240 coaxial machinegun and the AN/VRC-64 tactical FM radio. To determine memory structure for procedures, proximity analyses (Friendly, 1979) were performed on verbal recall of all tasks and for hands-on performance of the tasks where sequential performance of task steps was not required.

Findings:

1. Proximity analyses confirmed that armor crewmen organize their memory for procedures according to the hierarchical goal structure of the task.

2. For both verbal recall and hands-on performance, armor crewmen in entry-level training were superior to crewmen assigned to armor crews in an operational unit. However, no systematic differences between groups in memory organization were found.

3. For the entry-level group, memory structures derived from verbal recall were highly indicative of hands-on structures. This was less so for the operational unit group.

Utilization of Findings:

Simplified models of procedural memory organization were derived from the structural analyses. These models are potential aids for the training and sustainment of procedures.

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RETENTION OF ARMOR PROCEDURES:

A STRUCTURAL ANALYSIS

Johnson (1981) has pointed out that the nature of human tasks in advanced man-machine systems is rapidly changing from primarily skilled acts to tasks more procedural in character. This is particularly true of modern armor systems. In older tanks (e.g., the M48A5 and M60A1), tasks such as ranging to the target and leading a moving target have a large skill component. With the advent of the laser range finder and automatic lead components built into the fire control system of newer tanks (e.g., the M60A3 and M1), these tasks have become largely automated and therefore easier to perform. However, as these armor systems become easier to operate, the attendant pre- and post-operations procedures required by the systems grow more complex and therefore more difficult to learn (Black & Kraemer, 1981). Complicating this training problem is the fact that procedural tasks are particularly susceptible to forgetting over periods of no practice (e.g., Schendel, Shields, & Katz, 1978; Shields, Goldberg, & Dressel, 1978). Research is needed exploring new and better approaches to training and sustaining complex procedural skills.

Glaser (1982) has argued that instructional design should be more closely allied with scientific research on memory and cognition. Specifically, he proposed that instruction should be designed to foster the acquisition of cognitive structures associated with competent performance. In recent years, there have been some significant advances in specifying the structure of memory (see Friendly, 1980 and Reitman & Rueter, 1980, for reviews). A description of the memory structure for an armor procedure can provide the basis from which a theoretically oriented training and sustainment program may be developed. In the present paper, methods for describing memory structure were applied to some typical armor procedures.

In an earlier attempt to specify the memory organization for armor procedures, Morrison and Goldberg (1982) developed some rational analytic techniques for deriving memory structure. Task analytic guidelines were based on three assumptions about procedural memory structure: (1) memory for a procedure is organized around task goals, (2) task goals are hierarchically related, and (3) each hierarchical node is limited to no more than five subordinate branches. This approach proved useful in providing preliminary representations of likely memory structures. However, there were some serious limitations to the analysis procedures. For one, the cognitive guidelines were so general that the analytic process depended largely on the analyst's subjective interpretation of task goals. But even with more objective techniques, the task structure derived by the analyst may not necessarily correspond to the memory structures that soldiers actually use to remember procedures.

In contrast to the previous technique, Friendly (1979) developed an objective method for deriving the memory structure of free recall lists from the performance of learners. His method, called proximity analysis, is based on the assumption that items grouped together in memory tend to cluster together at recall. Thus, the pattern of response proximities reveals the organization

of memory. Proximity analysis begins by obtaining estimates of temporal or ordinal proximity on an item-by-item basis. The proximities are then subjected to a hierarchical cluster analysis. The product of the proximity analysis is a graphical representation of memory structure. Although proximity analysis has only been applied to free recall of verbal lists, this objective technique has application to retention of procedures. One purpose of the present research was to modify proximity analysis for deriving the organization of soldier performance on procedural tasks.

As stated earlier, one notable characteristic of procedural skills is their tendency to be forgotten over time. For instance, Osborn, Campbell, and Harris (1979) documented declines in armor task performance over the period between basic training and field unit assignment. Perhaps the decrements in skill levels were associated with changes in memory organization. Because proximity analysis is based on learners' responses, changes to memory structure can be measured as a function of time. To investigate this possibility, memory structures produced by armor crewmen in the final phase of entry-level training were compared to the structures of armor crewmen assigned to an operational field unit.

Soldier memory performance was tested by both verbal recall of the procedure and actual performance on the operational equipment (hands-on performance). Verbal recall had some advantages over hands-on performance as a memory performance measure. The most important advantage was that the temporal relations between emitted task elements were less ambiguous for recall than actual task performance. The principle drawback to testing verbal recall was that the memory organization used for verbal performance may not be identical to that used for hands-on performance. Accordingly, structures derived from either verbal or hands-on performance were compared wherever possible.

OBJECTIVES

The research objectives of the present project were as follows:

1. To derive the structure of memory for armor procedures from the retention performance of armor crewmen.

2. To determine whether the derived memory structures change over time.

3. To compare memory structures derived from verbal recall with those derived from hands-on performance.

METHOD

Research Participants

Two groups of armor crewmen (MOS 19E) participated in the present research project. One group was made up of 12 soldiers in the 1st Armor One Station Unit Training Brigade at Fort Knox (OSUT soldiers). The OSUT soldiers were in the final phase of the 13-week basic armor training course and had received training on all tasks of interest. The second group consisted of 12 soldiers

drawn from the 194th Armored Brigade, a Forces Command unit at Fort Knox (UNIT soldiers). Length of service for UNIT personnel ranged from five months to over five years, and their grades varied from E-1 to E-5.

Tasks

Procedural tasks were defined as those accomplished by a fixed set of discrete motor actions. Selected tasks were those which soldiers typically perform from memory, i.e., without benefit of job aids. Using these criteria, two subject areas were chosen from the Armor OSUT Program of Instruction: the M240 coaxial machinegun and the AN/VRC-64 tactical FM radio. Specific tasks are described below.

a. Clear the M240. The object of clearing is to unload the weapon and place the bolt in its forward (safe) position so that the weapon cannot be accidentally discharged.

b. Load the M240. The purpose of loading is to insert ammunition in the weapon and prepare it for firing.

c. Immediate Action for the M240. Immediate action is the loader's response to announcements of stoppage in firing caused by some weapon malfunction.

d. Disassemble the M240. The object of this task is to field strip the weapon for periodic maintenance.

e. Assemble/Functions Check the M240. For this task, the soldier reassembles the field-stripped weapon, then checks the operation of the weapon to determine if it is properly assembled.

f. Operate the AN/VRC-64. The purpose of this task is to ready the tank radio equipment for operation.

For purposes of analysis, tasks were classified as either sequential or nonsequential. Sequential tasks were those whose steps had to be performed in a certain order to accomplish task goals. In contrast, nonsequential procedures did not follow a fixed order of task elements. The mechanical training tasks of clearing, loading, and immediate action were sequential; whereas disassembly, assembly, and radio operation were nonsequential. In addition, assembly could be performed in any order whereas the functions check had a particular sequence. For that reason, assembly/functions check task was analyzed as two separate procedures.

Testing Procedure

All research participants were initially interviewed to assess their hands-on experience with each of the tasks. Following the interview, soldiers were tested individually on their verbal recall of procedures. They were instructed to state each procedure in a step-by-step manner while the tester recorded the responses on audio tape. To aid and clarify their recall, soldiers were shown photocopies of the M240 and AN/VRC-64 taken from technical manuals.

At the last station, hands-on tests on each task were administered to soldiers individually. Their performance on the operational equipment was videotaped. The experimenter later transcribed both audio and video tapes into written protocols.

Error Analysis

For nonsequential tasks, total errors (omissions and commissions) were recorded for each soldier. For sequential tasks, total errors also included errors of sequence. Sequence errors were defined in relation to other recalled or performed elements and not in terms of absolute ordinal position. That is, if a soldier recalled the first element last but committed no other error, a single sequence error was recorded even though all elements were recalled in the wrong ordinal position.

Differences between OSUT and UNIT training/testing criteria for some of the tasks complicated the procedure for scoring errors. For the clear task, UNIT soldiers were taught to close the cover before releasing the bolt forward; in contrast, OSUT personnel were told to close the cover after releasing the bolt. To reconcile the differences, both variations in order were accepted as correct. A similar difference was discovered in the assemble and disassemble tasks where UNIT soldiers removed/replaced the cover while OSUT soldiers merely open/closed the cover. Either set of responses was acceptable. More difficult to reconcile were differences in the radio operation task. OSUT soldiers were trained and tested on 17 specific steps for operating the radio, whereas the UNIT training/testing objective was to simply get the radio to work with less emphasis on exact procedure. Because the present concern was behavioral process, the task was scored on a step-by-step basis, which was probably disadvantageous for UNIT soldiers.

Proximity Analysis

The basic assumption for Friendly's (1979) proximity analysis technique is that "items that are grouped together in memory tend to be recalled closely together at the time of retrieval" (p. 88). Thus, the organization of memory for a procedure can be derived from the pattern of proximities in response. Proximities were defined in terms of output order or inter-response times. Friendly's method does not, however, account for response sequence, an important attribute of memory for procedure. In the present study, methods were developed for representing sequence as well as organization of recall. The analysis methods differed depending on the sequence requirements of the task. Therefore the analytic procedures for sequential and nonsequential tasks are described separately below.

Sequential tasks. Because sequential tasks were recalled in a fixed order, adjacent elements did not differ in proximity with respect to output order. In contrast, the time intervals between recalled elements were free to vary. Consequently, for sequential tasks, proximities were based on inter-response times. These times were recorded for verbal recall and not for hands-on performance. Two problems prevented measurement of times between hands-on responses. First, the onset and offset of a particular response could not be

reliably observed within the fluid series of actions which comprise hands-on performance of a procedure. Second, factors other than memory organization (e.g., spatial location of parts) can potentially control inter-response times. Thus, memory structures for sequential tasks were solely based on verbal recall and not hands-on performance.

Latencies (for each recalled element) were measured to the nearest second. Inter-response times were then defined as the arithmetic difference between latencies for each pair of recalled elements. The inter-response times were combined into proximity values for a group by taking the median times for that group. (Medians were used because of the marked positive skew of the inter-response times.) The medians were then entered into an element-by-element proximity matrix, and Johnson's (1967) maximum method of hierarchical cluster analysis was applied. Appendix A presents a detailed illustration of the cluster analysis procedure as it applies to the functions check task. The analysis results were displayed on a coordinate grid. To represent order, task elements were simply listed on the baseline in the prescribed sequence from left to right.

Nonsequential tasks. For nonsequential tasks, soldiers could recall or perform response elements in any order. Consequently, both inter-response times and output order could be used as measures of proximity. In fact, both generate similar structures. However, output order had two advantages over inter-response time as a measure of proximity. First, output order was more stable than inter-response time, especially without restrictions on order of recall or performance. Second, output order was obtainable from hands-on performance as well as verbal recall allowing comparisons of structures derived from both performance measures. Thus, output order was used as the proximity measure for nonsequential tasks.

The ordinal output position was determined for each task element either performed or recalled. The arithmetic difference in output order was then calculated for every pair of elements. Proximity values were defined as the mean of those differences for each of the two groups. As described above, proximity values were arranged in an element-by-element matrix and a cluster analysis was applied. In contrast to the previous method, however, the left-to-right ordering of the hierarchical structure was determined by soldiers' responses. Transition probabilities were used to arrange elements in sequence as they combined into clusters. For instance, suppose elements i and j formed a first order cluster. The cluster was listed as $i \rightarrow j$ if $p\ (i \rightarrow j) > p(j \rightarrow i)$. Similar rules were used for ordering higher order units.

Missing data. Although proximity analysis did not require error-free performance from every soldier, reliable estimates of proximity required at least a few data points. Therefore task elements remembered by fewer than three soldiers in either group were dropped from the proximity matrices and the corresponding hierarchical structures.

RESULTS AND DISCUSSION

Hands-on Experience

The initial survey of research participants confirmed that, in comparison to UNIT personnel, OSUT soldiers had more recent hands-on experience on the armor procedures in question. The OSUT soldiers received refresher training on the tasks just prior to their mid-cycle test which had occurred 1-3 weeks before the present test. The last hands-on experience reported by UNIT soldiers was in connection with Skill Qualification Tests (SQTs). UNIT soldiers reported having taken SQTs 1-6 months prior to the present study.

In contrast to the recency findings, the UNIT soldiers had the advantage in terms of performance frequency for most procedures. Table 1 shows that, compared to the OSUT group, UNIT soldiers reported significantly higher frequencies of performance on Clear, Disassemble, and Assemble/Functions Check the M240 as well as Operate the AN/VRC-64. However, there were no differences in UNIT and OSUT groups in the reported frequencies for Load the M240 and Immediate Action for the M240. Examination of SQT objectives revealed that these latter tasks were not included on armor tests. These findings suggest that UNIT soldiers received little or no retraining on Load and Immediate Action after entry-level training in the Armor School.

Table 1

Median Estimated Frequencies of Task Performance

	Group		Significance
	OSUT	UNIT	of Difference[a]
Clear the M240	11.0	42.5	<.05
Load the M240	15.0	13.0	N.S.
Immediate Action for the M240	13.5	10.5	N.S.
Disassemble the M240	9.0	45.0	<.05
Assemble/Functions Check the M240	9.0	47.5	<.05
Operate the AN/VRC-64	7.5	37.5	<.01

[a]Because of the marked positive skew of the estimates, differences were tested by the Mann-Whitney U.

Verbal Recall

Errors. Table 2 contrasts OSUT and UNIT soldiers on the average total number of errors committed while verbally recalling each of the seven tasks. UNIT soldiers made significantly more errors than OSUT soldiers on Clear the M240, Load the M240, Immediate Action for the M240, and Operate the AN/VRC-64 with the differences being particularly large for the latter three tasks. The verbal performance differences between OSUT and UNIT groups on Load the M240 and Immediate Action for the M240 may be attributable to memory losses since UNIT soldiers apparently had little or no retraining on these tasks. However, possible decrements in recall of the radio operation task were confounded with training/testing differences as discussed in the Error Analysis section.

Structure. To present the results of the structural analyses, Clear the M240 and Operate the AN/VRC-64 were chosen to represent sequential and nonsequential tasks, respectively. The proximity matrices and hierarchical structures for these procedures are presented and discussed below. Proximity matrices and hierarchical structures for the remaining tasks are presented in Appendices B and C.

Table 2

Mean Errors of Verbal Recall

	Group		Significance
	OSUT	UNIT	of Difference[a]
Sequential Tasks			
Clear the M240	1.4	3.2	<.01
Load the M240	1.3	5.0	<.01
Immediate Action for the M240	4.1	12.0	<.01
Functions Check the M240	1.0	1.0	N.S.
Nonsequential Tasks			
Disassemble the M240	0.8	0.8	N.S.
Assemble the M240	1.2	1.3	N.S.
Operate the AN/VRC-64	0.8	6.0	<.01

[a] t-test of difference between independent means.

The temporal proximities between recalled elements of Clear the M240 are presented for OSUT and UNIT groups in Table 3. The resulting hierarchical structures are shown in Figure 1. As represented by Clear the M240, sequential task structures were organized around temporal subgoals. Starting at the top, both OSUT and UNIT structures were segmented into two parts representing the two sequential subgoals. Elements of the first part related to removing all sources of ammunition from the weapon. The second group of elements pertained to returning the weapon to a safe state after unloading. Intermediate hierarchical relations differed between OSUT and UNIT structures, but the lowest relationships showed exactly the same pairings of elements. These first-order relationships reflected a few mechanical and safety rules which are basic constraints to order: (a) The safety must be in FIRE in order to move the bolt either forward or backward; (b) the safety must be in SAFE before opening the cover; and (c) the firing chamber is accessed by lifting the feed tray.

Operate the AN/VRC-64 represents the nonsequential tasks. The proximity matrix is presented in Table 4 and the resulting hierarchical structure is shown in Figure 2. In contrast to the temporal organization of sequential tasks, nonsequential procedures were organized around the spatial relationships between the AN/VRC-64 components. In both OSUT and UNIT structures, there were three discernable subgoals which related to major radio components: connect/adjust the audio accessories, operate the audio frequency amplifier, and operate the radio-transmitter. The latter two subgoals were joined at a superordinate level presumably because the audio frequency amplifier is located on top of the radio-transmitter, both of which are separated from the crewman's control box and audio accessories. Even at the lowest hierarchical level, the spatial organization is still obvious. For instance, the elements "adjust RT volume" and "set function switch on SQUELCH" do not have to be performed in any particular order. However, because the volume control and function switch are located close together on the radio-transmitter, both OSUT and UNIT soldiers recalled the two steps together in their protocols. Consequently, these elements were directly connected at a low hierarchical level.

Although there were some minor discrepancies between OSUT and UNIT task structures, the similarities were more striking than the differences. To obtain a numerical index of structural isomorphism, entries in the OSUT and UNIT proximity matrices were correlated for the clear task and the radio operation task. The correlations were quite high (.93 and .82, respectively) indicating similar patterns of proximities. These findings suggested that changes in recall levels do not necessarily imply changes in memory organization.

Hands-On Performance

Errors. Table 5 contrasts OSUT and UNIT groups on the average number of errors committed during hands-on performance of procedures. The group differences in performance paralleled those found in the recall data except that the difference on Clear the M240 for hands-on performance was not significant. Thus, the group differences in verbal recall provided a good indication of the relative skill levels of the groups.

Table 3

Proximities (Seconds) Between Recalled Elements of Clear the M240

OSUT Matrix

Elements:	1	2	3	4	5	6	7	8	9	10	11
1. Check if in FIRE.	---	2.1	4.2	7.2	8.8	11.2	12.5	15.8	18.5	18.8	20.0
2. Pull bolt to rear.		---	2.3	5.8	7.0	9.5	11.0	13.5	17.0	16.8	18.2
3. Place in SAFE.			---	2.0	4.5	5.2	7.0	11.5	15.0	14.8	16.2
4. Open cover.				---	2.5	3.8	6.0	9.3	11.0	12.0	14.0
5. Remove ammo belt.					---	2.2	3.5	6.8	9.5	9.0	10.8
6. Lift feed tray.						---	2.0	5.1	10.5	8.0	9.5
7. Look & feel in chamber.							---	3.2	7.0	5.8	7.0
8. Lower feed tray.								---	4.0	3.8	5.8
9. Close cover.									---	2.3	2.3
10. Place in FIRE.										---	1.8
11. Pull trigger/ride bolt forward.											---

UNIT Matrix

Elements:	1	2	3	4	5	6	7	8	9	10	11
1. Check if in FIRE.	---	2.0	3.8	5.7	10.0	11.0	12.0	14.8	13.5	15.5	19.0
2. Pull bolt to rear.		---	2.0	4.0	8.0	9.5	11.0	13.0	13.0	16.0	17.5
3. Place in SAFE.			---	2.3	6.5	7.5	9.5	12.0	14.5	16.5	20.0
4. Open cover.				---	3.5	3.5	6.5	10.3	10.0	13.0	14.5
5. Remove ammo belt.					---	2.3	4.2	7.0	8.5	10.5	13.0
6. Lift feed tray.						---	2.5	10.0	6.2	11.0	13.0
7. Look & feel in chamber.							---	5.0	4.8	7.0	9.5
8. Lower feed tray.								---	2.0	3.0	4.5
9. Close cover.									---	2.0	3.2
10. Place in FIRE.										---	1.9
11. Pull trigger/ride bolt forward.											---

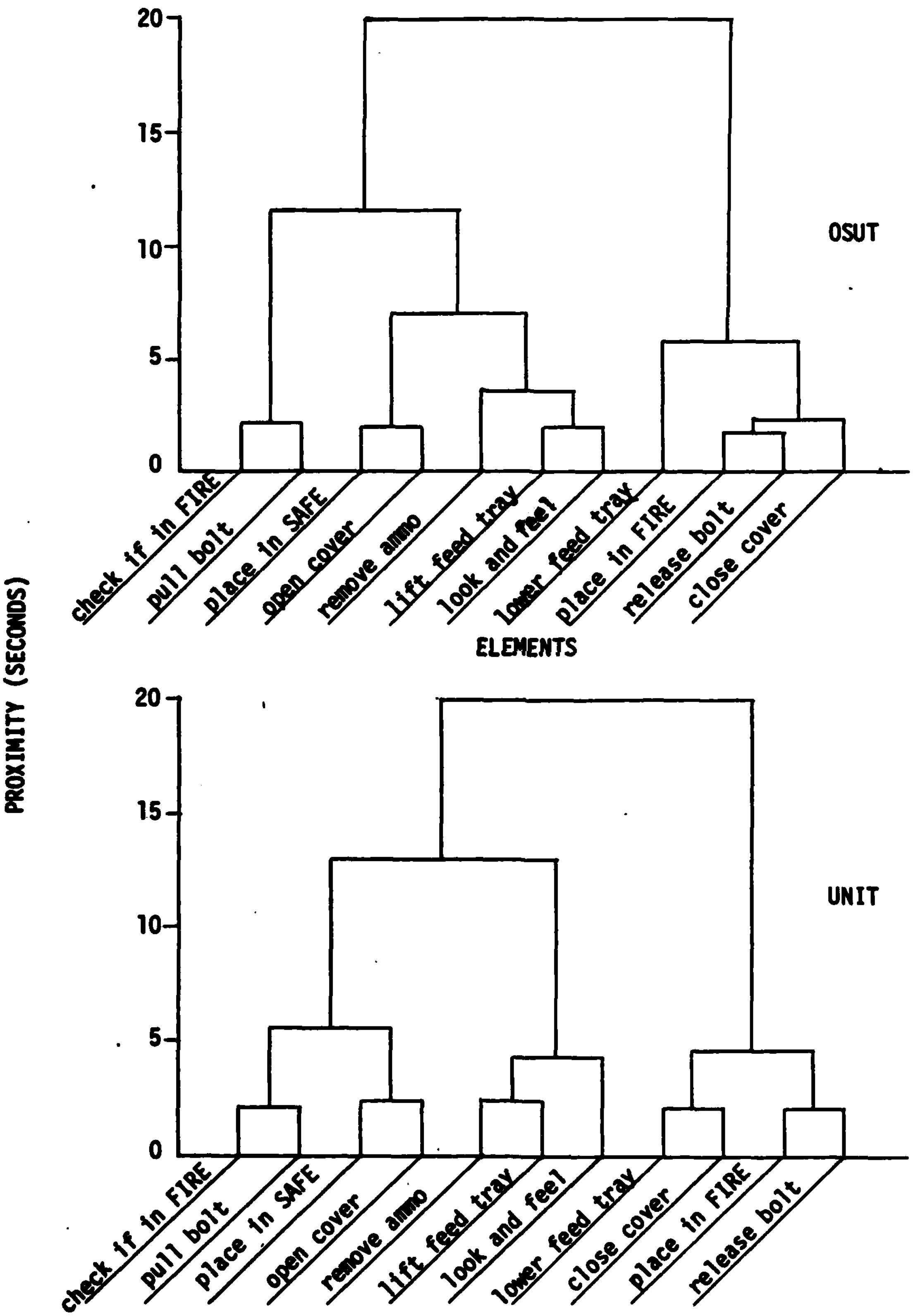

Figure 1. Hierarchical structure for verbal recall of Clear the M240.

Table 4

Proximities (Output Position) Between Recalled Elements of Operate the AN/VRC-64

OSUT Matrix

Elements:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. Place CVC helmet on head.	---	1.0	2.2	2.4	3.4	4.8	5.0	8.9	9.8	10.6	11.8	11.2	11.3	11.6	11.8	12.8	12.7	14.6
2. Adjust boom mike.		---	1.5	2.5	2.7	4.0	4.3	8.2	9.0	9.8	11.0	10.2	10.6	10.7	11.0	12.5	12.2	13.0
3. Put helmet switch in center position.			---	1.3	2.0	3.1	3.3	6.7	7.5	8.3	9.5	8.9	9.1	9.6	9.8	11.8	11.2	12.2
4. Connect quick disconnect.				---	1.0	2.5	2.6	6.0	6.8	7.6	8.8	9.1	9.2	9.0	9.3	10.9	10.4	12.4
5. Audio cables.					---	1.4	1.6	5.6	6.4	7.2	8.4	7.8	8.0	8.2	8.4	9.6	9.3	11.0
6. Adjust control box VOL.						---	1.0	4.0	4.8	5.7	6.8	6.3	6.4	6.7	6.8	8.2	7.8	9.4
7. Turn MONITOR to ALL.							---	3.8	4.7	5.5	6.8	6.2	6.3	6.6	6.8	8.0	7.7	9.4
8. Set RAD TRANS on CDR+CREW.								---	1.0	2.0	2.8	6.4	6.6	4.7	4.8	7.3	6.2	7.9
9. Set INT ACCENT on ON.									---	1.0	2.0	5.4	5.8	4.1	4.6	6.1	6.1	7.8
10. Set MAIN PWR on NORM.										---	1.2	4.8	5.2	3.6	4.0	5.6	5.6	7.2
11. Switch PWR CKT BKR to ON.											---	4.7	4.0	3.2	3.5	4.8	5.1	6.6
12. Switch amp. PWR to ON.												---	1.0	3.2	3.2	3.1	3.2	3.8
13. Switch SPKR to OFF.													---	3.4	3.6	3.0	3.2	3.6
14. Set FUNCTION on SQUELCH.														---	1.0	2.3	2.2	3.6
15. Adjust R-T VOL.															---	2.2	1.8	3.3
16. Set BAND selector.																---	1.6	1.8
17. Set FREQ controls.																	---	1.8
18. Set ANT FREQ CONTROL.																		---

UNIT Matrix

Elements:	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
3. Put helmet switch in center position.	---	4.5	3.8	2.3	3.2	7.0	4.7	6.2	6.4	8.0	8.7	8.0	10.0	8.3	8.2	6.5
4. Connect quick disconnect.		---	1.0	5.2	5.2	6.8	5.3	5.3	6.9	5.0	6.2	8.2	8.0	8.8	7.3	7.0
5. Connect audio cables.			---	4.2	4.6	6.2	5.0	5.0	7.2	5.7	6.7	7.8	7.7	7.9	5.9	6.4
6. Adjust control box VOL.				---	1.0	3.2	3.2	4.2	4.8	8.4	9.7	6.8	8.0	10.0	5.8	7.8
7. Turn MONITOR to ALL.					---	4.6	4.7	4.8	3.9	5.6	6.0	5.8	7.6	6.0	4.7	5.6
8. Set RAD TRANS on CDR+CREW.						---	1.5	1.9	2.3	5.4	6.0	3.8	4.6	5.9	4.6	5.2
9. Set INT ACCENT on ON.							---	1.0	3.3	5.2	5.8	4.1	4.4	6.3	4.6	4.9
10. Set MAIN PWR on NORM.								---	2.9	4.4	6.1	4.6	4.3	6.3	4.8	5.1
11. Switch PWR CKT BKR to ON.									---	3.9	4.2	3.3	4.0	4.4	4.4	4.1
12. Switch amp PWR to ON.										---	1.0	4.1	3.7	3.7	4.2	2.7
13. Switch SPKR to OFF.											---	3.5	3.5	3.0	3.4	1.7
14. Set FUNCTION on SQUELCH.												---	1.0	2.2	2.9	3.1
15. Adjust R-T VOL.													---	2.4	2.6	2.6
16. Set BAND selector.														---	1.4	1.7
17. Set FREQ controls.															---	2.7
18. Set ANT FREQ CONTROL.																---

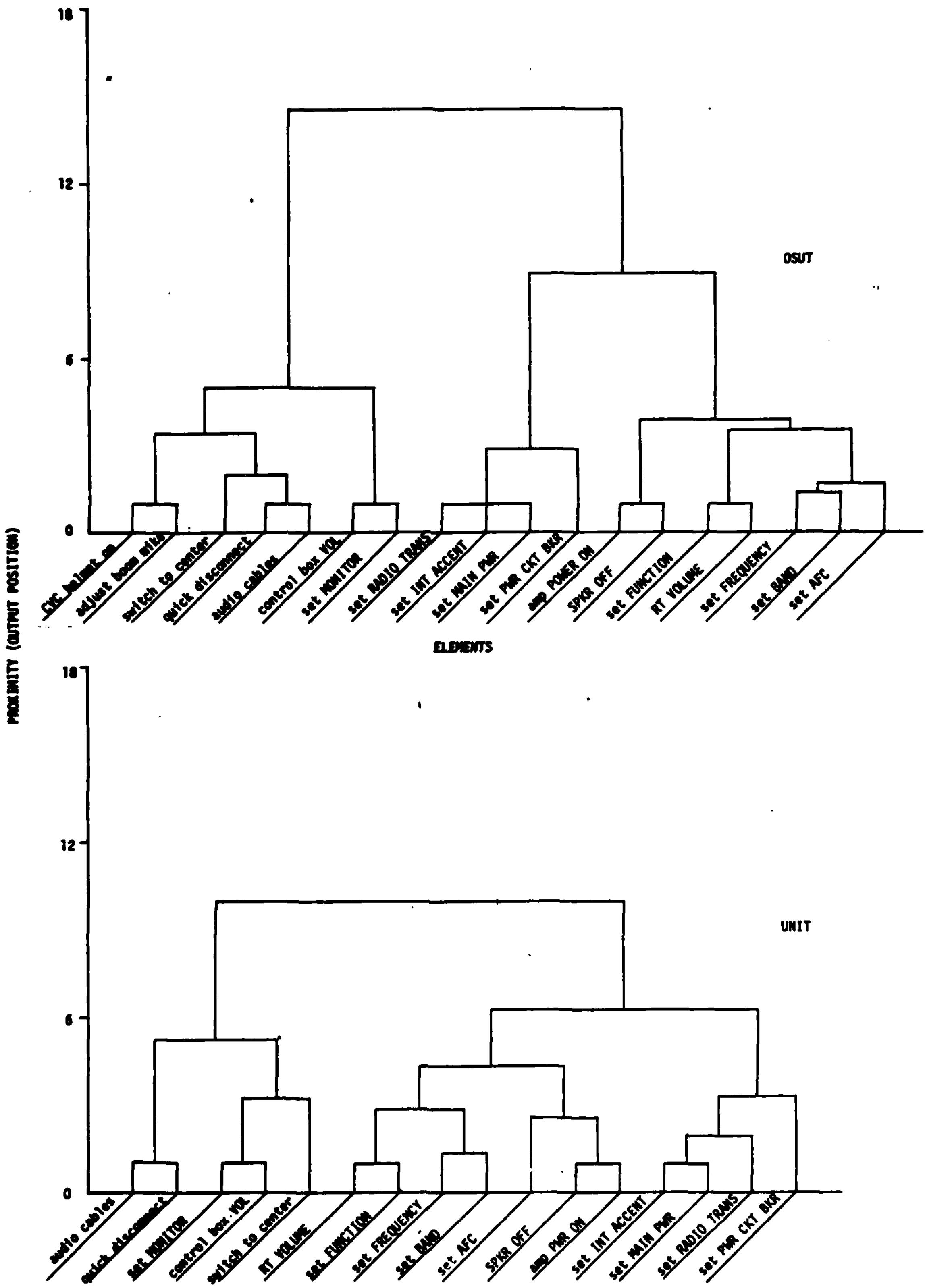

Figure 2. Hierarchical structure for verbal recall of Operate the AN/VRC-64.

Table 5

Mean Errors of Hands-On Performance

	Group		Significance of Difference[a]
	OSUT	UNIT	
Sequential Tasks			
Clear the M240	0.6	1.4	N.S.
Load the M240	1.3	5.0	<.01
Immediate Action for the M240	2.6	9.6	<.01
Functions Check the M240	0.9	1.0	N.S.
Nonsequential Tasks			
Disassemble the M240	0.1	0.1	N.S.
Assemble the M240	0.0	0.1	N.S.
Operate the AN/VRC-64	1.0	3.6	<.01

[a]*t*-test of difference between independent means.

Structure. For reasons given in the Proximity Analysis section, hands-on structures were derived only for nonsequential tasks. Operate the AN/VRC-64 was chosen as the representative task; the proximity matrix is given in Table 6 and the hierarchical structure is presented in Figure 3. Proximity matrices and hierarchical structures for the remaining nonsequential tasks are given in Appendices D and E. Figure 3 indicates that the hands-on structures were similar to the verbal structure. However, the correspondence of verbal and hands-on structures appears greater for the OSUT than the UNIT group. To measure that correspondence, entries in verbal and hands-on matrices were correlated separately for OSUT and UNIT soldiers. The correlations for all three nonsequential tasks (see Table 7) confirm a high degree of similarity between verbal and hands-on structures for OSUT soldiers but a lesser degree of correspondence in the UNIT structures.

A possible explanation for the differences in structural correspondence between verbal recall and hands-on performance was suggested by the author's informal observations of soldier performance during training and testing. Entry-level soldiers often recite steps as they perform procedures, especially in the early stages of learning. Also, novice soldiers often verbally rehearse procedures immediately prior to being tested. In contrast, more experienced soldiers do not verbalize procedures as often. During the present testing, some of the UNIT soldiers commented that, although they had performed the task many times, they were not used to verbalizing the steps. This anecdotal

Table 6

Proximities (Output Position) Between Performed Elements of Operate the AN/VRC-64

OSUT Matrix

Elements:	1	2	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. Place CVC helmet on head.	---	1.0	2.0	3.0	4.0	5.0	7.8	8.8	9.8	11.0	10.8	11.8	11.6	12.3	10.8	12.0	13.0
2. Adjust boom mike.		---	1.0	2.0	3.0	4.0	6.8	7.8	8.8	10.0	9.8	10.8	10.6	11.3	9.8	11.0	12.0
4. Connect quick disconnect.			---	1.0	2.0	3.0	5.8	6.8	7.8	9.0	8.8	9.8	9.6	10.3	8.8	10.0	11.0
5. Connect audio cables.				---	1.0	2.0	4.8	5.8	6.8	8.0	7.8	8.8	8.6	9.3	7.8	9.0	10.0
6. Adjust control box VOL.					---	1.0	3.8	4.8	5.8	7.0	7.6	8.6	8.6	9.3	7.8	9.0	10.0
7. Turn MONITOR to ALL.						---	2.8	3.8	4.8	6.0	5.8	6.8	6.6	7.3	5.8	7.0	8.0
8. Set RAD TRANS on CDR+CREW.							---	1.0	2.0	3.0	6.5	6.8	4.6	5.3	4.9	5.7	8.0
9. Set INT ACCENT on ON.								---	1.0	2.0	6.2	6.5	3.9	4.7	4.2	5.0	7.3
10. Set MAIN PWR on NORM.									---	1.0	6.0	6.2	3.3	4.1	3.7	4.4	6.8
11. Switch PWR CKT BKR to ON.										---	5.9	6.0	2.9	3.6	3.5	4.2	6.5
12. Switch amp. PWR to ON.											---	1.0	4.9	4.6	3.1	3.1	2.9
13. Switch SPKR to OFF.												---	4.9	4.6	3.1	3.1	2.6
14. Set FUNCTION on SQUELCH.													---	1.0	2.2	2.0	3.7
15. Adjust R-T VOL.														---	2.2	1.9	3.1
16. Set BAND selector.															---	1.2	3:1
17. Set FREQ controls.																---	2.3
18. Set ANT FREQ CONTROL.																	---

UNIT Matrix

Elements:	1	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. Place CVC helmet on head.	---	2.6	3.4	10.6	5.8	8.4	7.7	7.2	7.3	4.2	6.3	6.3	6.4	5.9	6.2	6.1
4. Connect quick disconnect.		---	2.2	8.4	4.1	8.6	7.4	6.8	6.9	4.4	6.8	7.2	8.6	6.1	6.4	6.9
5. Connect audio cables.			---	8.8	3.2	7.2	7.2	6.8	8.4	6.6	7.8	7.5	7.9	6.8	7.2	6.9
6. Adjust control box VOL.				---	6.8	3.5	4.8	5.4	4.8	7.2	6.8	6.8	5.8	7.0	6.8	6.6
7. Turn MONITOR to ALL.					---	5.8	5.0	5.1	6.6	5.2	6.4	6.6	6.3	6.1	6.5	6.4
8. Set RAD TRANS on CDR+CREW.						---	1.4	2.1	4.0	7.0	6.8	6.4	5.6	4.6	5.6	6.6
9. Set INT ACCENT on ON.							---	1.1	3.8	4.9	7.0	5.6	5.7	4.8	5.0	5.7
10. Set MAIN PWR on NORM.								---	4.4	4.6	6.3	5.2	5.2	4.6	4.8	5.4
11. Switch PWR CKT BKR to ON.									---	4.3	5.5	4.6	4.8	4.6	4.3	4.2
12. Switch amp. PWR to ON.										---	2.0	3.9	4.0	2.7	2.9	2.3
13. Switch SPKR to OFF.											---	4.2	4.2	3.2	3.5	3.3
14. Set FUNCTION on SQUELCH.												---	1.4	3.6	2.9	3.1
15. Adjust R-T VOL.													---	4.0	3.3	3.5
16. Set BAND selector.														---	1.0	2.2
17. Set FREQ controls.															---	1.8
18. Set ANT FREQ CONTROL.																---

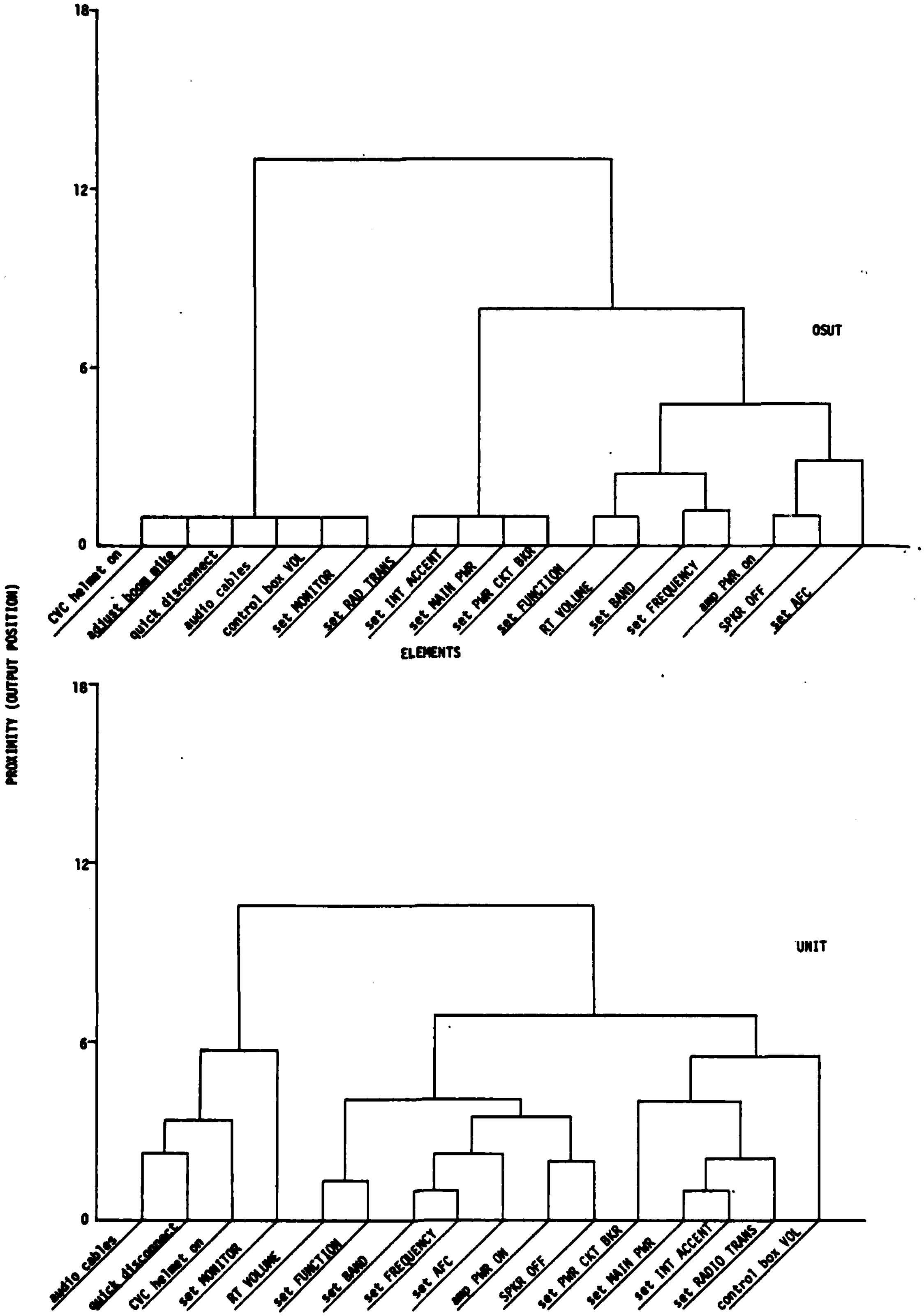

Figure 3. Hierarchical structure for hands-on performance of Operate the AN/VRC-64.

Table 7

Correlations Between Verbal and Hands-On Proximity Matrices

Tasks	Group		Significance of Difference[a]
	OSUT	UNIT	
Disassemble the M240	.87	.70	<.01
Assemble the M240	.90	.52	<.01
Operate the AN/VRC-64	.95	.75	<.01

[a]Differences between correlations were tested using a "jack-knife" procedure for estimating sampling variances (Mosteller & Tukey, 1968).

evidence suggested that armor crewmen verbalize task elements to initially acquire and sustain task proficiency, but that the verbal component drops out over time. Other researchers have also noted changes in the verbal component of motor tasks over time (e.g., Fitts, 1964). However, these studies typically show that a decrease in the verbal component is associated with an increase in skill performance as a function of practice. Here, skill performance declined over time. Research is needed to clarify the role of verbalization in both the acquisition and sustainment of procedural skills.

GENERAL DISCUSSION

Results from the proximity analyses provided convincing evidence that armor crewmen do indeed organize their memory for procedures according to the hierarchical goal structure of the tasks. In accordance with previous research (e.g., Osborn, Campbell, & Harris, 1979; Shields, Goldberg, & Dressel, 1978), the verbal recall and hands-on performance data both indicated decrements in soldier skill levels from basic training to field unit assignment. However, the decrease in skill level was not correlated with any observable changes in memory organization. Finally, structures derived from verbal recall were highly indicative of hands-on structures for soldiers still in training, but less indicative for soldiers in the field. It was speculated that these differences were due to differences between the groups in verbal coding of the procedures.

Researchers have raised questions about the validity of the proximity analysis technique. A central notion to proximity analysis is that proximities are symmetrical. That is, the distance from element a to element b must be equal to the distance from b to a. Reitman and Rueter (1980) criticized this aspect of proximity analysis arguing that recall is inherently asymmetrical. In defense of his method, Friendly maintained that information about response order may not be important in determining organization per se (1979, p. 104). The present solution was to determine order separately from determining structure. In contrast, Reitman and Rueter (1980) provided a more direct method which identified ordered chunks from recall protocols. However, their method

required repeated, error-free recall of verbal items from different starting points in the list. It seems unrealistic to impose these data collection requirements on soldiers recalling complicated procedures. But perhaps the best defense of the current procedure is in the results: The present technique yielded clearly interpretable task structures.

Related to the validity issue is the question of how the empirically derived task structures obtained in the present study compare to the structures derived from rational analysis of task goals (Morrison & Goldberg, 1982). Clear the M240 and Operate the AN/VRC-64 were again used as example tasks. Figure 4 presents the rationally derived structure for Clear the M240. Comparison of this structure with Figure 1 reveals similar high-level divisions of elements related to unloading the weapon and returning the weapon to a safe state. However, there are some interesting discrepancies between the structures. For one, the empirical structure shows a direct link between "place in SAFE" and "open cover" which does not exist in the rationally derived structure. This relation reflects the training admonition to always place the weapon in SAFE before opening the cover. Comparison of rational and empirical structures for Operate the AN/VRC-64 also reveals similarities and differences. According to the rational analysis (Figure 5), the task is divided into two functions: Operate the VIC-1 Intercom and Operate the VRC-64 Radio-Transmitter. Because the audio frequency amplifier is necessary for operation of the intercom, the audio amplifier component is identified as part of the former subgoal. In contrast, the empirical analysis (Figure 2) shows that the cluster of steps relating to the audio frequency amplifier is connected to the radio-transmitter cluster. As discussed in the previous section, this relationship reflects the spatial arrangement of components. Despite this difference in high-level task organization, many lower order structural relations were similar for the rational and empirical analyses. In sum, the rational analyses were predictive of many empirically derived relations. However, the empirical analyses differed from the rational analyses in significant ways.

Resnick (1976) has argued that rational and empirical task analyses provide useful information for instructional design. She suggested that rational analysis be used create an initial model of student performance which may be modified by later empirical analyses to provide a closer fit to actual performance. Following this suggestion, Figures 6 and 7 provide modifications of the previously presented structures which are consistent with the empirical findings of the present research. To simplify the figures, the structures were limited to only four levels of organization. As in the previous figures, each hierarchical node was given a short name descriptive of the corresponding subgoal function. The resulting modified structures provide a comprehensible, albeit somewhat idealized, model of memory organization.

What are the implications of the task structures for procedural training and sustainment? Research has indicated that simply making learners aware of task structure increases response organization and improves recall (e.g., Bower, Clark, Lesgold, & Winzenz, 1969; Diewart & Stelmach, 1978). Perhaps then, illustrations of task structure (such as those in Figures 6 and 7) may provide useful training and sustainment aids for procedural skills. But the question of how structural information may best be incorporated into hands-on training must be left to future research.

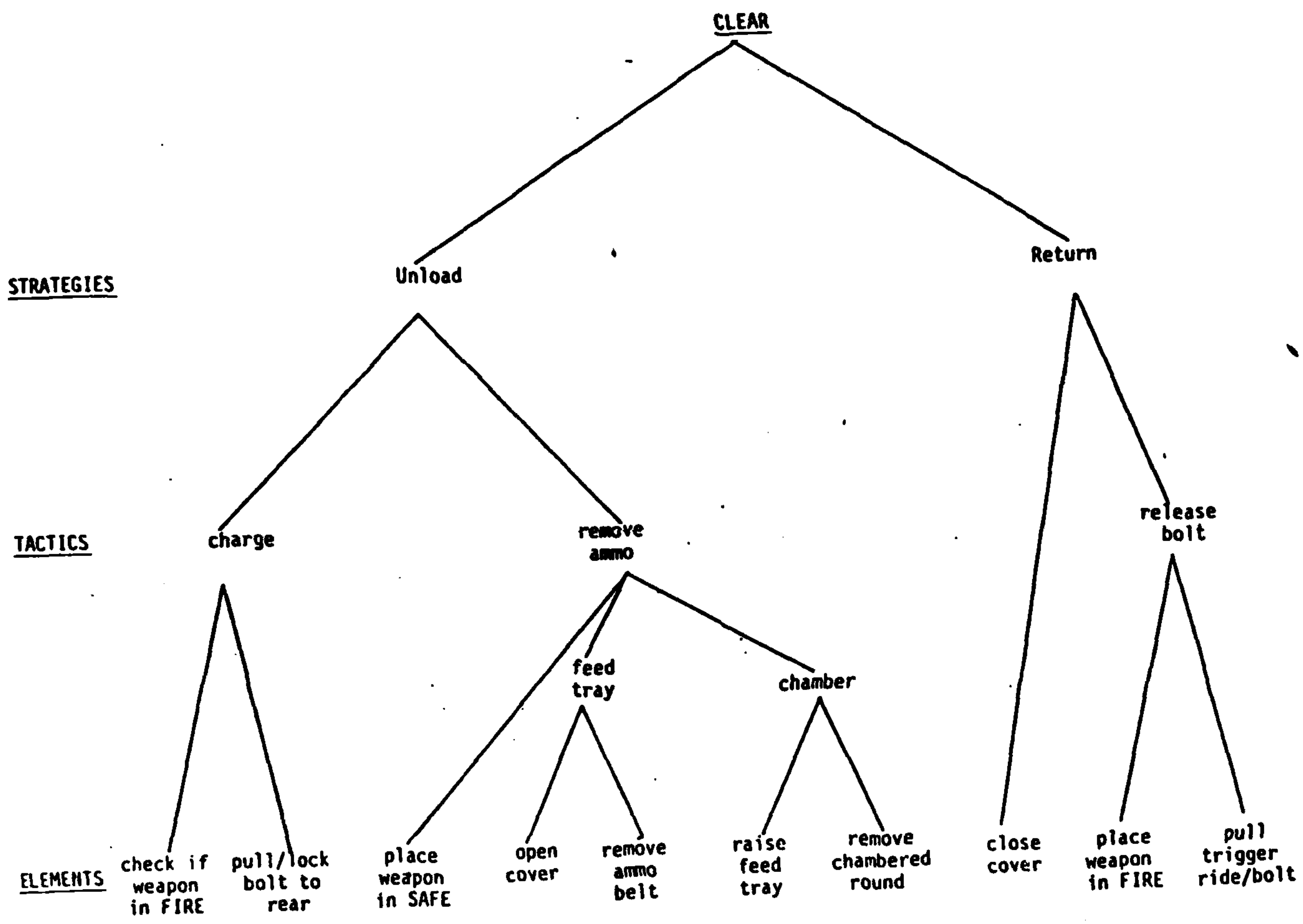

Figure 4. Rationally derived goal structure for Clear the M240 (from Morrison & Goldberg, 1982).

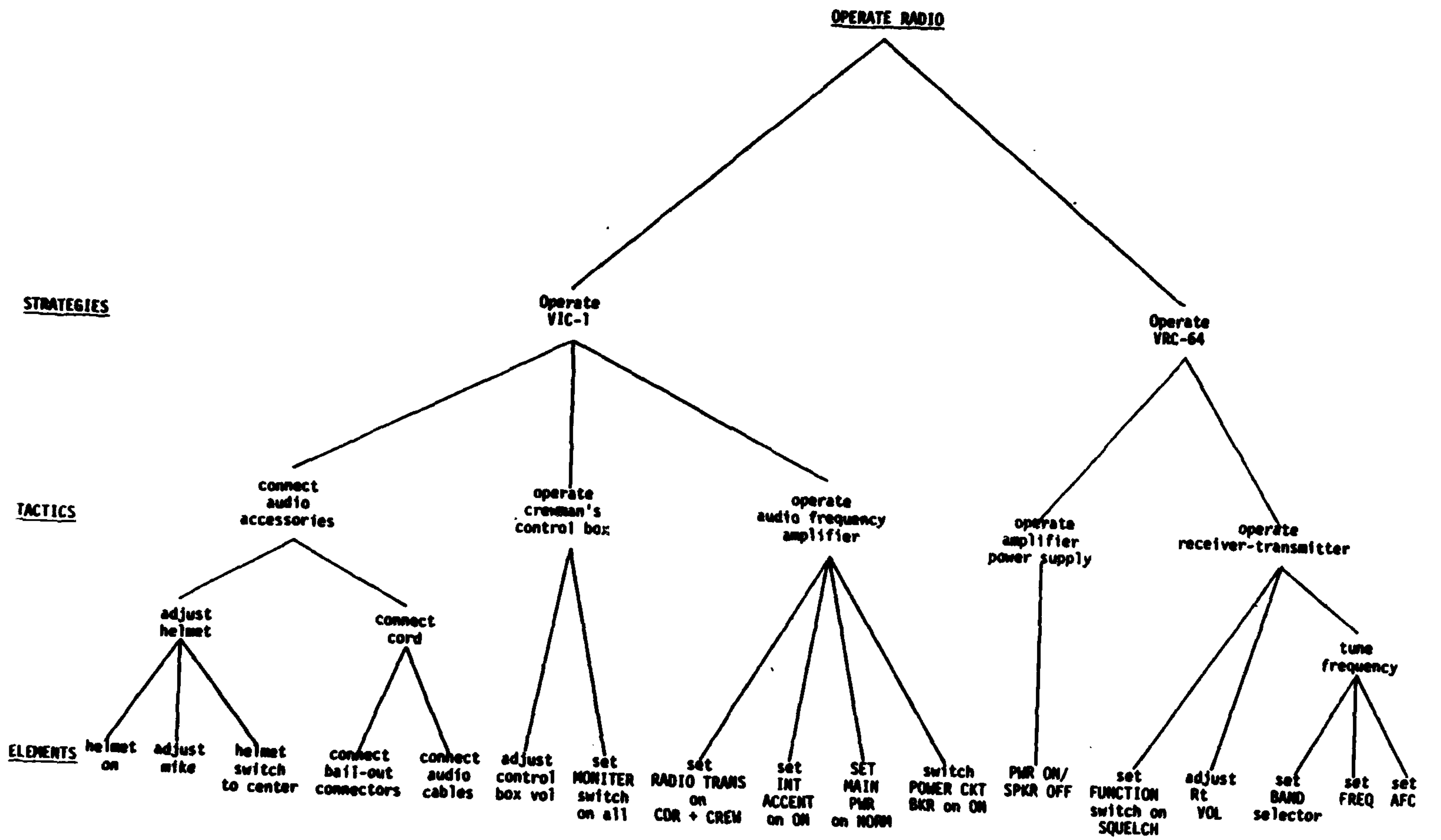

Figure 5. Rationally derived goal structure for Operate the AN/VRC-64 (from Morrison & Goldberg, 1982).

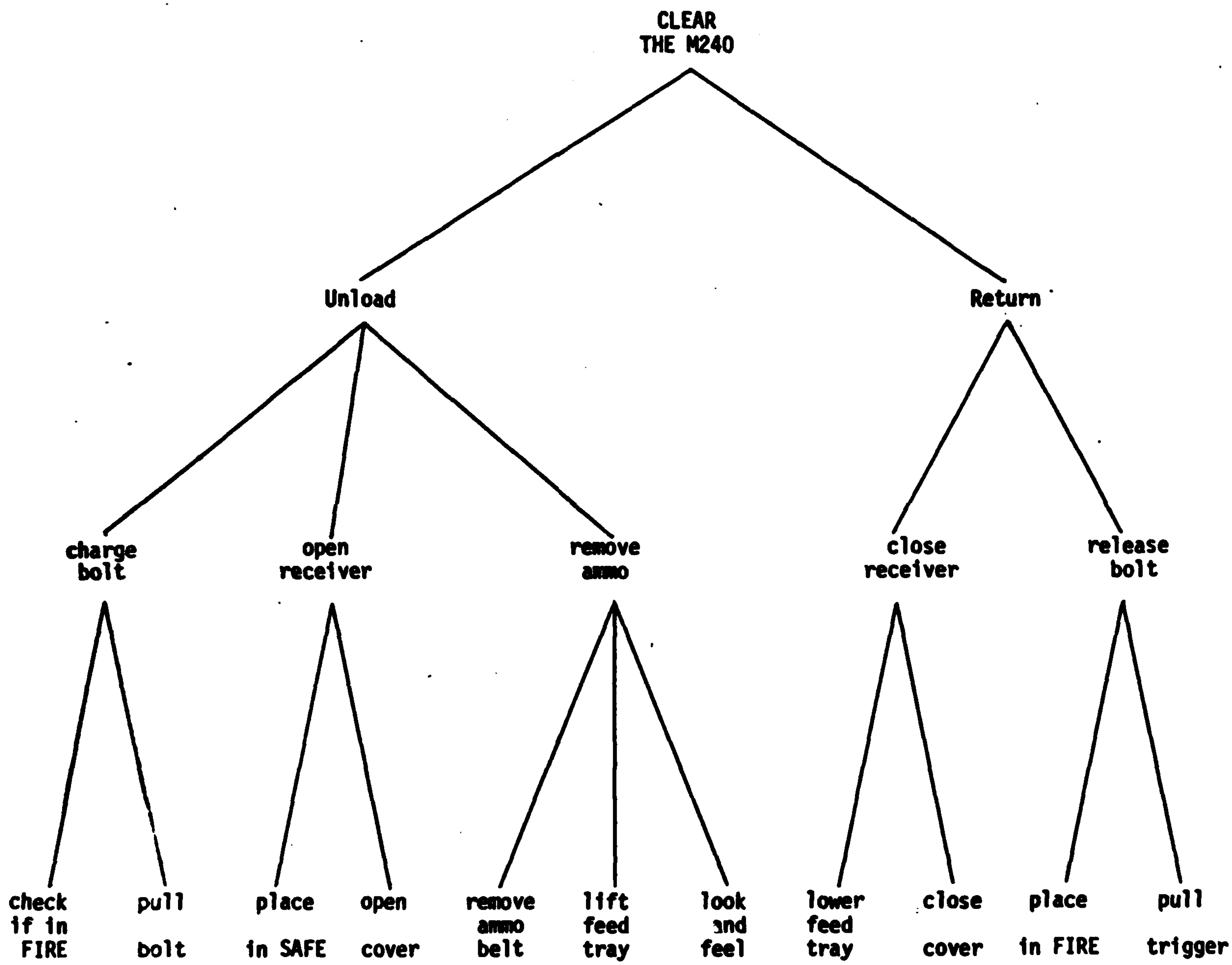

Figure 6. Modified goal structure for Clear the M240.

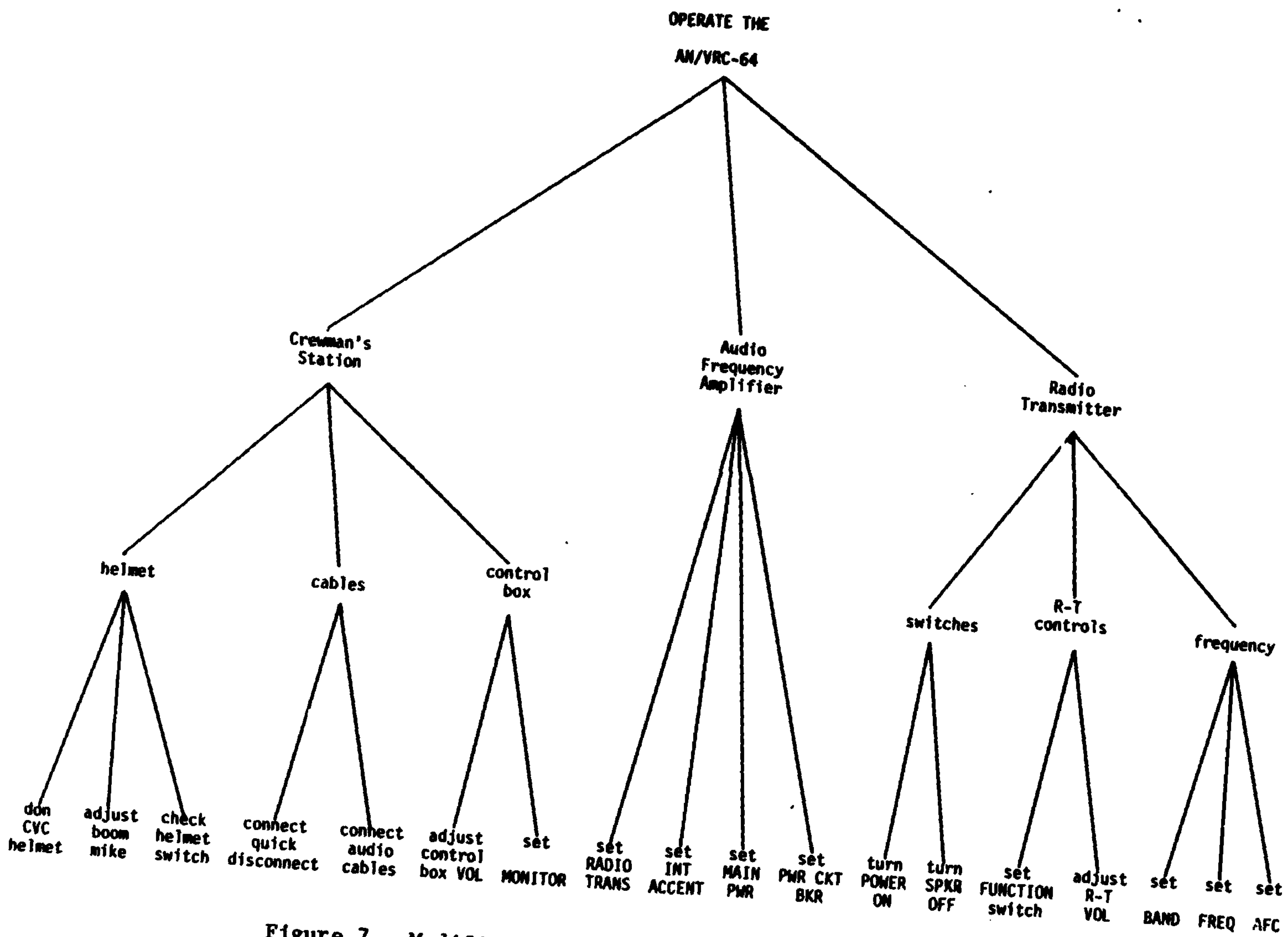

Figure 7. Modified goal structure for Operate the AN/VRC-64.

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APPENDIX A

ILLUSTRATION OF THE CLUSTER ANALYSIS PROCEDURE

These data are taken from the OSUT group's recall of the functions check task. The resulting structure is illustrated at the top of Figure C-3. The procedure for determining that structure is as follows:

1. Arrange the medians in an element-by-element proximity matrix. The elements are represented by number. The resulting matrix is:

	1	2	3	4	5	6
1	-	1.5	2.7	4.5	7.5	9.0
2		-	1.4	3.0	6.0	7.8
3			-	1.1	4.8	6.3
4				-	3.3	5.3
5					-	1.9
6						-

2. Find the smallest proximity value in the matrix (1.1). The corresponding pair of elements (3 and 4) are then joined at that valve of proximity, and the two elements are combined by taking the larger value at each cell combination. The reduced matrix is:

	1	2	3,4	5	6
1	-	1.5	4.5	7.5	9.0
2		-	3.0	6.0	7.8
3,4			-	4.8	6.3
5				-	1.9
6					-

3. Repeat the process on the reduced matrix. The smallest remaining value is 1.5. Therefore, elements 1 and 2 are joined at that value and their values are again combined. The resulting matrix is:

	1,2	3,4	5	6
1,2	-	4.5	7.5	9.0
3,4		-	4.8	6.3
5			-	1.9
6				-

4. Now join elements 5 and 6 at a proximity of 1.9. The reduced matrix is:

	1,2	3,4	5,6
1,2	-	4.5	9.0
3,4		-	6.3
5,6			-

5. Join cluster 1,2 and 3,4 at a proximity of 4.5. After combining cells, there is but one value remaining: 9.0.

6. Join cluster 1,2,3,4 with 5,6 at a proximity of 9.0 The matrix is now completely collapsed and the figure is complete.

APPENDIX B

PROXIMITY MATRICES FOR VERBAL RECALL

Table B-1

Proximities (Seconds) Between Recalled Elements of Load The M240

OSUT Matrix

Elements:	1	2	3	4	5	6	7	8	9
1. Check if in FIRE.	---	1.9	3.7	5.0	7.0	7.5	9.0	13.0	18.5
2. Pull bolt to rear.		---	2.0	3.4	6.0	7.5	9.8	11.8	16.5
3. Place in SAFE.			---	1.7	4.0	5.0	7.5	9.8	14.2
4. Open cover.				---	2.2	3.6	5.8	8.1	13.0
5. Raise feed tray.					---	1.6	3.1	5.3	11.2
6. Look & feel in chamber.						---	2.0	4.5	9.5
7. Lower feed tray.							---	2.2	7.0
8. Place ammo on tray.								---	2.5
9. Close cover.									---

UNIT Matrix

Elements:	1	2	3	4	8	9
1. Check if in FIRE.	---	1.5	3.8	4.0	8.0	10.0
2. Pull bolt to rear.		---	2.5	3.0	5.4	8.0
3. Place in SAFE.			---	1.5	4.5	10.0
4. Open cover.				---	2.2	5.0
8. Place ammo on tray.					---	3.0
9. Close cover.						---

Table B-2

Proximity (Seconds) Between Recalled Elements of Immediate Action For The M240

OSUT Matrix

Elements:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
(1st stoppage)																			
1. Wait 5 secs.	---	5.7	6.8																
2. Pull bolt to rear.		---	1.5																
3. Announce "up."			---																
(2d stoppage)																			
4. Wait 5 secs.				---	3.0	6.0	8.5	10.5	10.0	14.5	19.0	24.0	23.5	28.0	18.0	28.5	34.8	28.0	34.0
5. Pull bolt to rear.					---	2.2	3.7	5.0	7.7	9.8	12.8	16.0	18.3	21.8	24.0	25.0	30.5	30.0	31.0
6. Place in SAFE.						---	1.6	3.3	5.6	7.7	10.0	13.0	16.0	17.2	21.8	23.0	28.0	26.5	27.5
7. Open cover.							---	1.8	4.0	5.5	9.5	11.0	14.5	15.5	19.0	21.5	25.8	23.0	25.0
8. Remove ammo belt.								---	2.0	3.0	8.5	8.5	12.0	13.5	17.5	19.5	23.0	21.0	24.0
9. Lift feed tray.									---	1.3	4.5	7.8	10.2	11.2	15.0	17.5	21.5	20.5	22.5
10. Look & feel in chamber.										---	3.5	4.5	8.0	9.5	13.0	14.5	19.0	18.0	19.2
11. Place in FIRE.											---	4.2	5.5	5.2	8.5	10.5	13.5	13.5	15.5
12. Pull trigger/ride bolt forward.												---	1.5	2.5	8.5	9.5	11.2	12.2	13.3
13. Pull bolt to rear.													---	2.0	4.5	6.5	9.8	11.2	12.2
14. Place in SAFE.														---	3.5	6.0	8.8	9.8	10.8
15. Lower feed tray.															---	3.0	5.7	6.5	7.8
16. Place ammo on tray.																---	2.7	4.0	5.0
17. Close Cover.																	---	1.5	2.5
18. Place in FIRE.																		---	1.1
19. Announce "up."																			---

UNIT Matrix

Elements:	1	2	3	5	6	7	8	9	10	16	17	18	19
(1st stoppage)													
1. Wait 5 secs.	---	6.5	5.0										
2. Pull bolt to rear.		---	2.2										
3. Announce "up."			---										
(2d stoppage)													
5. Pull bolt to rear.				---	2.3	3.2	5.5	8.0	7.5	10.0	13.0	14.0	12.5
6. Place weapon in SAFE.					---	1.4	3.0	5.0	6.2	13.2	14.0	20.0	11.0
7. Open cover.						---	1.3	5.0	5.8	12.2	13.0	18.5	14.0
8. Remove ammo belt.							---	2.0	3.5	9.0	9.0	14.0	13.0
9. Lift feed tray.								---	0.8	9.0	9.0	13.5	13.5
10. Look & feel in chamber.									---	5.0	5.2	8.0	7.5
16. Place ammo on tray.										---	0.5	4.5	5.5
17. Close cover.											---	2.5	5.0
18. Place weapon in FIRE.												---	1.5
19. Announce "up."													---

Table B-3

Proximities (Seconds) Between Recalled Elements of Functions Check The M240

OSUT Matrix

Elements:	1	2	3	4	5	6
1. Check if in FIRE.	---	1.5	2.7	4.5	7.5	9.0
2. Pull bolt to rear.		---	1.4	3.0	6.0	7.8
3. Place weapon in SAFE.			---	1.1	4.8	6.3
4. Pull trigger.				---	3.3	5.3
5. Place weapon in FIRE.					---	1.9
6. Pull trigger/ride bolt forward.						---

UNIT Matrix

Elements:	1	2	3	4	5	6
1. Check if in FIRE.	---	1.2	2.8	4.0	6.2	7.2
2. Pull bolt to rear.		---	1.5	3.2	5.2	6.0
3. Place weapon in SAFE.			---	1.8	4.3	6.0
4. Pull trigger.				---	3.0	5.0
5. Place weapon in FIRE.					---	1.2
6. Pull trigger/ride bolt forward.						---

Table B-4

Proximities (Output Position) Between Recalled Elements of Disassemble the M240

OSUT Matrix

Elements:	1	2	3	4	5	6
1. Remove barrel.	---	1.2	2.8	3.4	2.9	3.9
2. Remove buffer assembly.		---	1.7	2.2	1.9	2.9
3. Remove driving rod & spring.			---	1.1	1.8	2.4
4. Remove bolt assembly.				---	1.4	1.8
5. Remove trigger assembly.					---	1.7
6. Remove (raise) cover.						---

UNIT Matrix

Elements:	1	2	3	4	5	6
1. Remove barrel.	---	2.1	2.6	2.9	3.2	3.0
2. Remove buffer assembly.		---	1.4	2.4	2.1	2.4
3. Remove driving rod & spring.			---	1.1	2.1	2.2
4. Remove bolt assembly.				---	1.9	1.9
5. Remove trigger assembly.					---	1.8
6. Remove (open) cover.						---

Table B-5

Proximities (Output Position) Between Recalled Elements of Assemble the M240

OSUT Matrix

Elements:	1	2	3	4	5	6	7
1. Replace (close) cover.	---	3.0	2.2	3.0	2.5	2.7	3.0
2. Replace trigger assembly.		---	2.2	1.8	1.7	1.4	2.4
3. Insert charger handle.			---	3.7	3.0	1.8	1.0
4. Replace bolt assembly.				---	1.4	2.4	4.1
5. Replace driving rod & spring.					---	1.5	3.1
6. Replace buffer assembly.						---	1.7
7. Replace barrel.							---

UNIT Matrix

Elements:	1	2	3	4	5	6	7
1. Replace (close) cover.	---	2.4	3.7	2.4	2.4	2.8	3.2
2. Replace trigger assembly.		---	1.3	2.2	1.8	1.6	2.9
3. Insert charger handle.			---	2.3	3.3	2.3	3.5
4. Replace bolt assembly.				---	1.1	2.4	3.5
5. Replace driving rod & spring.					---	1.3	3.0
6. Replace buffer assembly.						---	2.2
7. Replace barrel.							---

APPENDIX C

HIERARCHICAL STRUCTURES FOR VERBAL RECALL

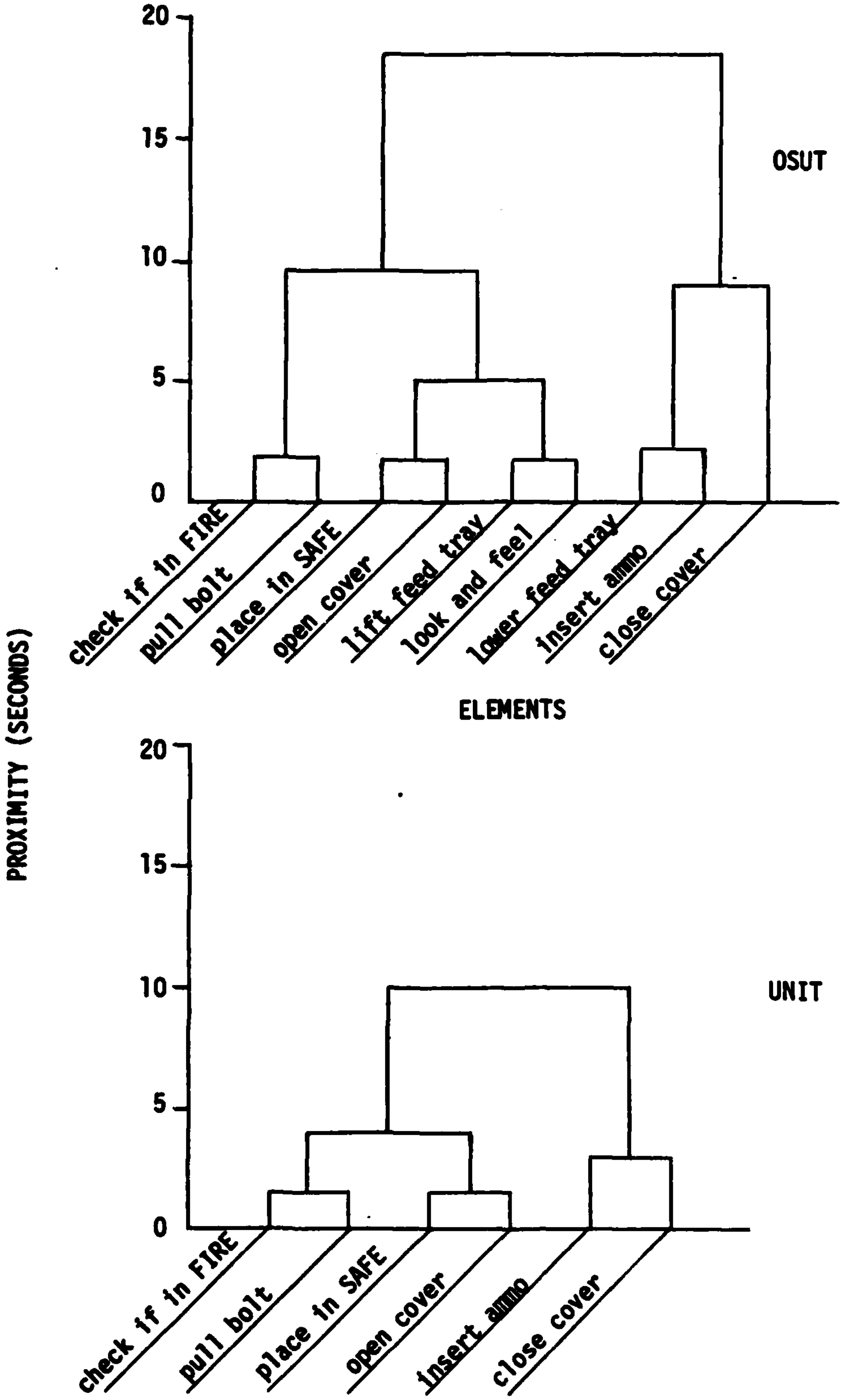

Figure C-1. Hierarchical structure for verbal recall of Load the M240.

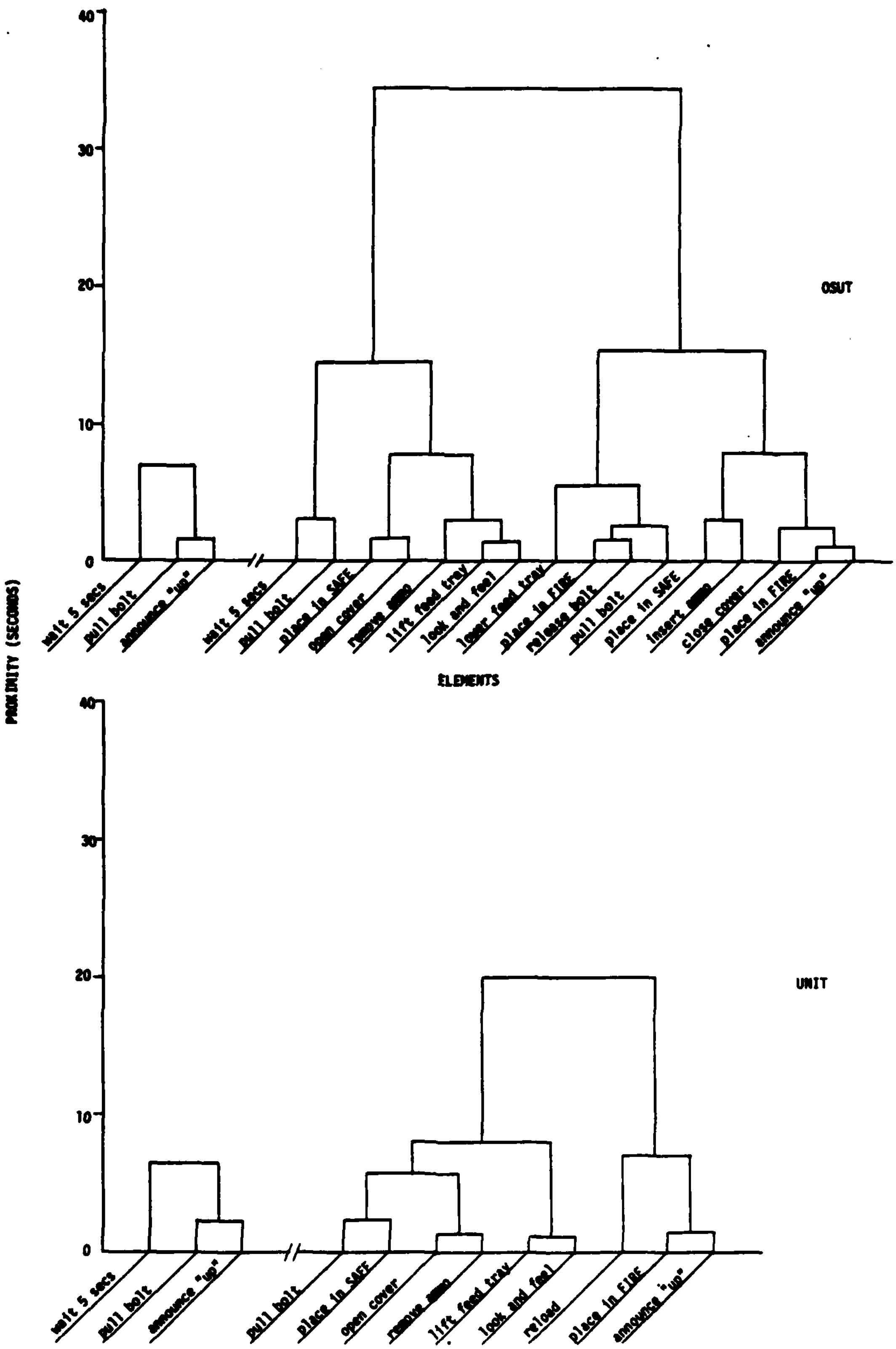

Figure C-2. Hierarchical structure for verbal recall of Immediate Action on the M240.

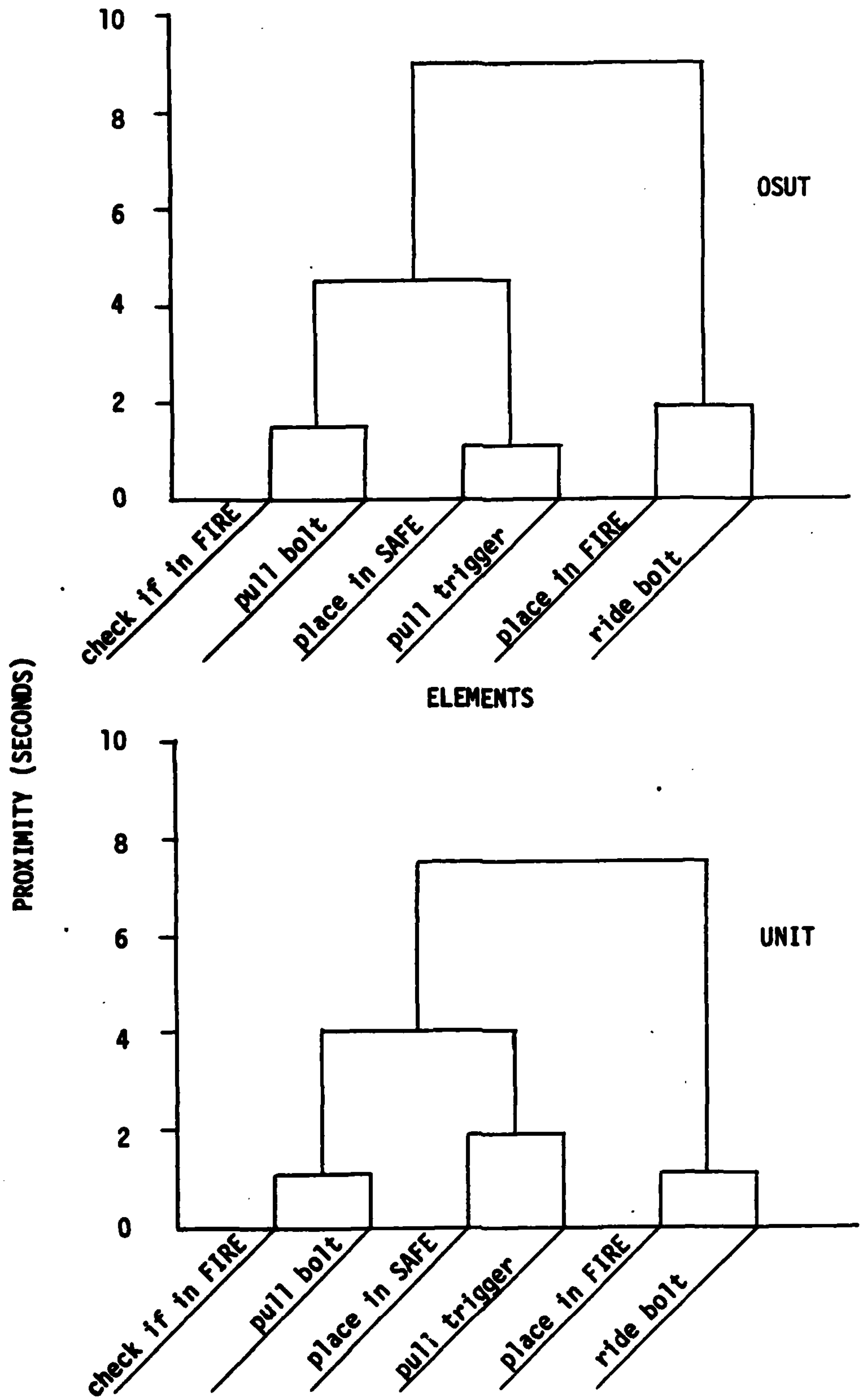

Figure C-3. Hierarchical structure for verbal recall of Functions Check the M240.

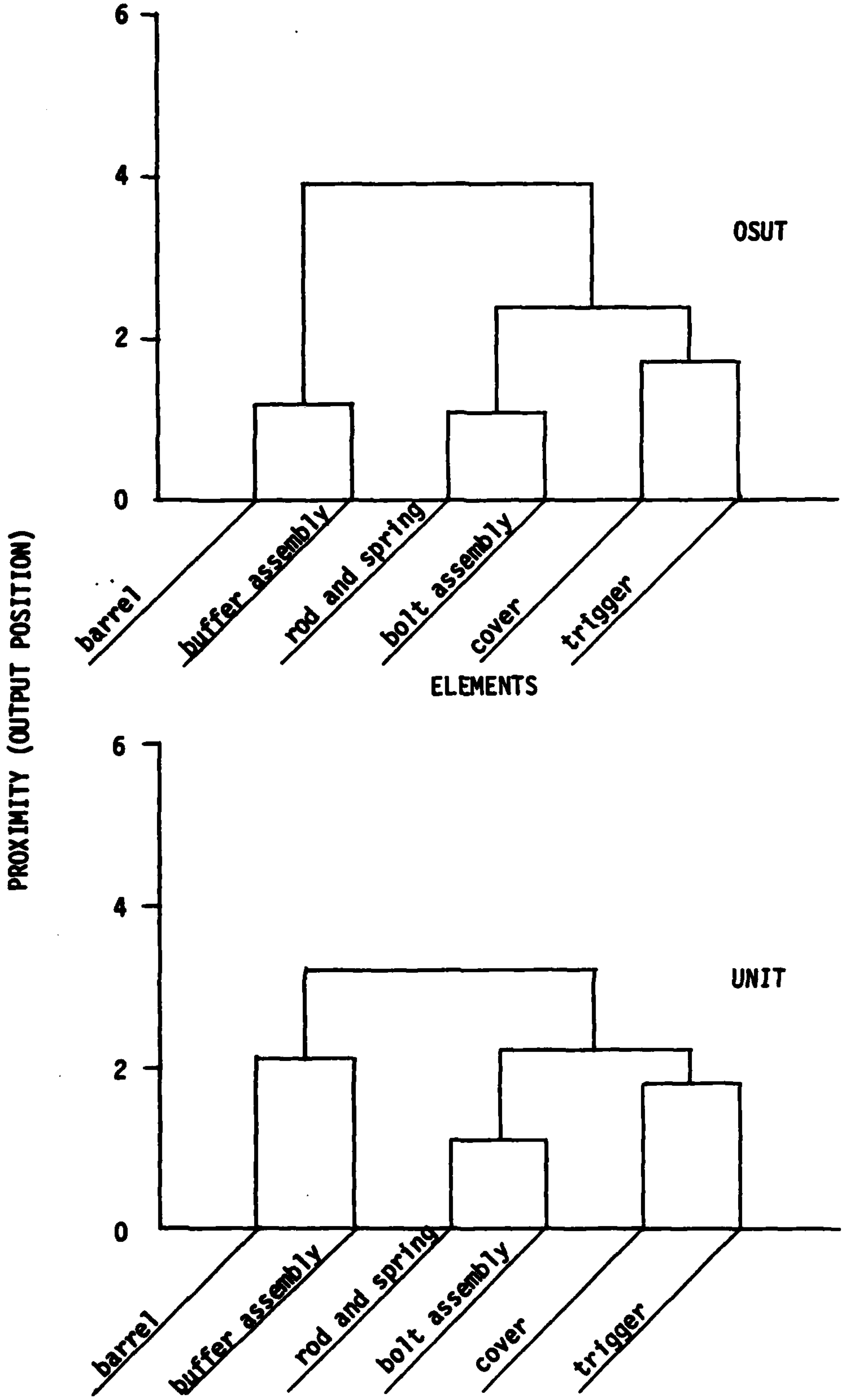

Figure C-4. Hierarchical structure for verbal recall of Disassemble the M240.

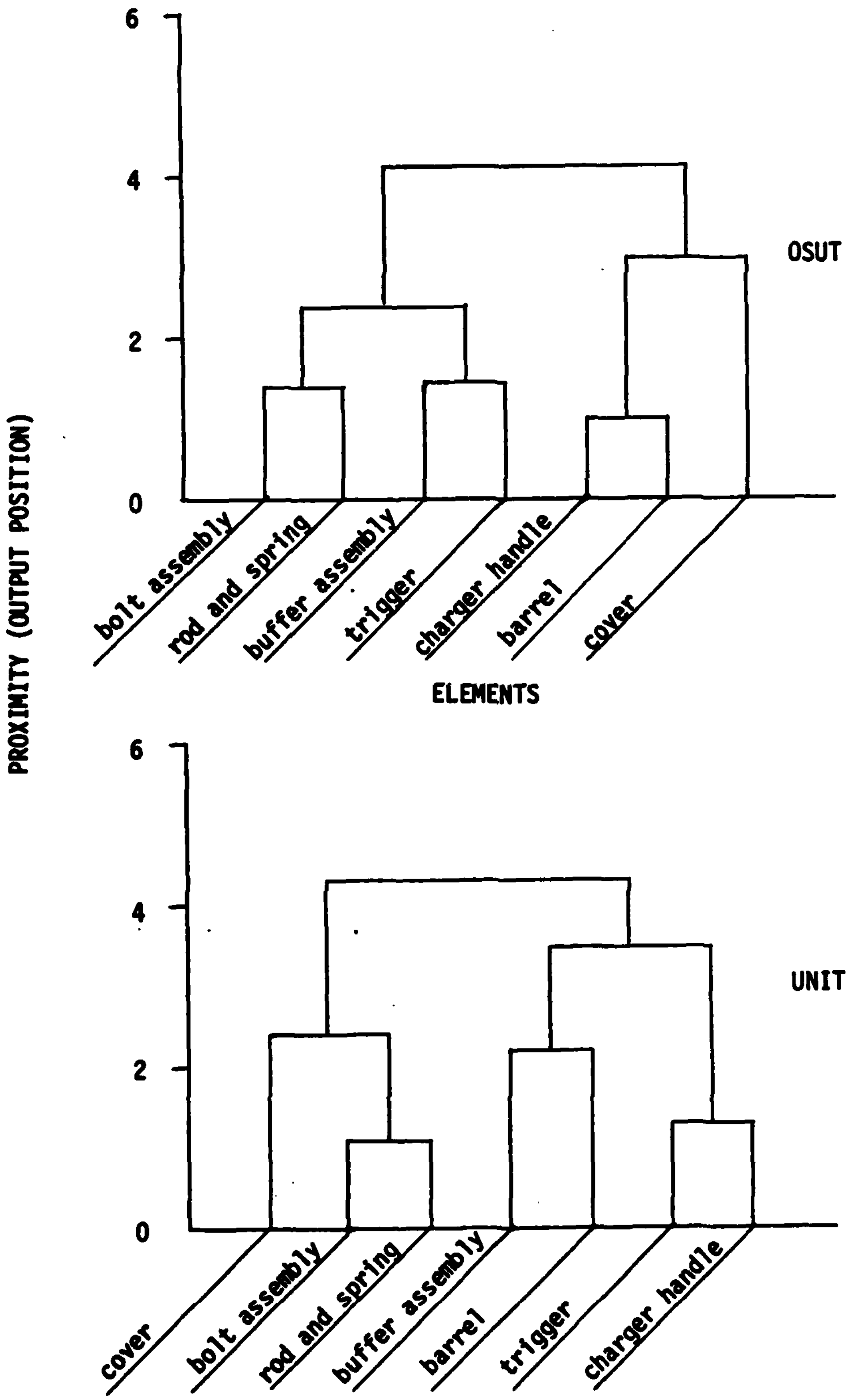

Figure C-5. Hierarchical structure for verbal recall of Assemble the M240.

APPENDIX D

PROXIMITY MATRICES FOR

HANDS-ON PERFORMANCE

Table D-1

Proximities (Output Position) Between Performed Elements of Disassemble the M240

OSUT Matrix

Elements:	1	2	3	4	5	6
1. Remove barrel.	---	1.2	2.9	4.2	3.2	3.5
2. Remove buffer assembly.		---	1.8	3.0	2.2	2.4
3. Remove driving rod & spring.			---	1.2	1.9	1.6
4. Remove bolt assembly.				---	2.0	1.8
5. Remove trigger assembly.					---	1.8
6. Remove (raise) cover.						---

UNIT Matrix

Elements:	1	2	3	4	5	6
1. Remove barrel.	---	4.7	3.4	1.8	1.8	3.4
2. Remove buffer assembly.		---	4.8	3.2	3.0	4.3
3. Remove driving rod & spring.			---	4.4	3.5	4.6
4. Remove bolt assembly.				---	4.5	4.4
5. Remove trigger assembly.					---	3.4
6. Remove (raise) cover.						---

Table D-2

Proximities (Output Position) Between Performed Elements of Assemble the M240

OSUT Matrix

Elements:	1	2	3	4	5	6	7
1. Replace (close) cover.	---	2.4	3.2	3.3	2.4	2.2	3.1
2. Replace trigger assembly.		---	2.5	2.5	1.9	1.7	2.8
3. Insert charger handle.			---	4.3	3.3	1.8	1.3
4. Replace bolt assembly.				---	1.2	3.2	5.2
5. Replace driving rod & spring.					---	1.9	3.9
6. Replace buffer assembly.						---	2.0
7. Replace barrel.							---

UNIT Matrix

Elements:	1	2	3	4	5	6	7
1. Replace (close) cover.	---	2.9	2.5	4.1	2.8	1.7	1.3
2. Replace trigger assembly.		---	2.2	2.1	2.0	2.3	3.4
3. Insert charger handle.			---	3.4	3.2	3.1	2.8
4. Replace bolt assembly.				---	1.2	2.6	4.4
5. Replace driving rod & spring.					---	1.3	3.2
6. Replace buffer assembly.						---	1.8
7. Replace barrel.							---

APPENDIX E

HIERARCHICAL STRUCTURES FOR HANDS-ON PERFORMANCE

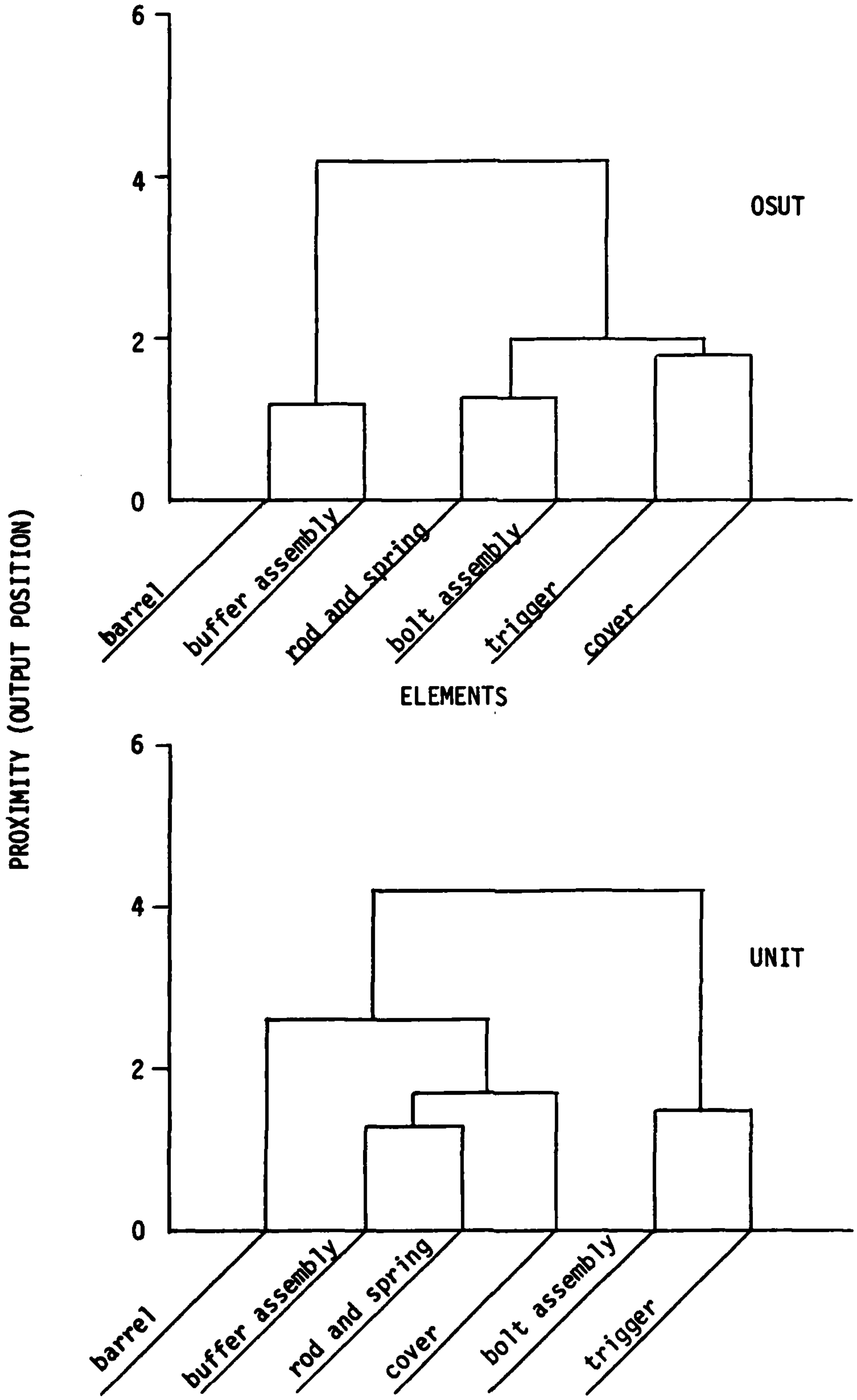

Figure E-1. Hierarchical structure for hands-on performance of Disassemble the M240.

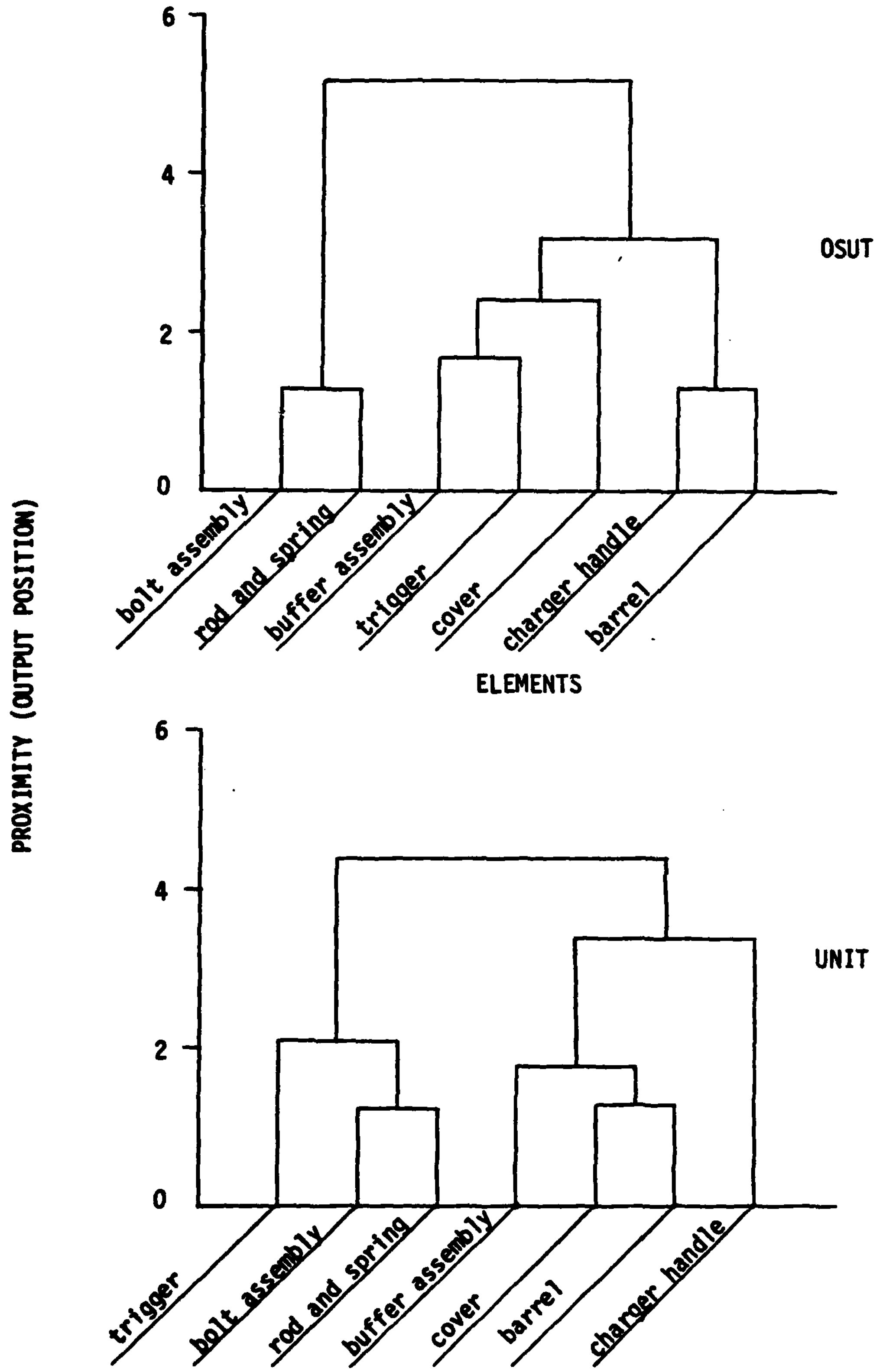

Figure E-2. Hierarchical structure for hands-on performance of Assemble the M240.